National Bureau of Standards

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Moisture Determination by Electrolytic Film

An improved method for measuring small amounts of water vapor in gases, developed by E. R. Weaver of the Bureau's gas chemistry laboratory, depends essentially on the change in electrical resistance of an electrolytic film as it absorbs water vapor. Such a method has the advantages of speed, simplicity, high sensitivity, and wide range. It is very flexible in operation and is readily adapted to numerous applications, such as measuring the moisture-permeability of membranes, detecting minute concentrations of combustible gas in air or of oxygen in combustible gas, determining water vapor in aviators' oxygen or in liquid carbon dioxide, measuring the capacity of drying agents, determining the water content of organic liquids and solutions, and measuring the relative humidity in small or comparatively inaccessible spaces under rapidly changing conditions.

The principle of the method has been employed at the Bureau in various devices for some time. A thin film of liquid, which may be phosphoric acid, or a solution of sulfuric acid or other electrolyte in a gelatin or plastic binding material, is spread over the surface of a solid insulator between metallic electrodes. The electrolyte tends to reach equilibrium with the water vapor in the surrounding gas and to form a solution, the electrical conductance of which is a measure of the concentration of water vapor in the gas. To utilize this phenomenon, some sensitive instrument for measuring or comparing electrical resistances, and a means of calibrating the film by comparison with a gas of known moisture content, are necessary. Because of polarization, alternating current must be used.

In its original form, the utility of the method was limited by the fact that the films had high temperature coefficients of resistance and did not retain their calibrations, that recalibration was a laborious task, and that no entirely satisfactory instrument was available for measuring very small alternating currents. In the development at the Bureau of the well-known electric hygrometer, which automatically transmits measurements of humidity from small sounding balloons in the upper air to ground stations, F. W. Dunmore removed the first of these limitations by improving the stability of the films. However, this was done at a sacrifice of speed and sensitivity.

Finally, the wartime need for a method of determining the dryness of aviators' oxygen led to the design of apparatus permitting rapid calibration. This feature now makes it possible to retain the inherent advantages of speed and sensitivity for low ranges of humidity and, at the same time, to eliminate most of the difficulty caused by impermanence of calibration and changes in film conductance with temperature. In making a determination with this apparatus, either or both of the pressures of a sample of gas of known moisture content and of the unknown sample are adjusted until they have the same concentration of water as shown by equal electrical resistance of the detecting film. The water concentration of the known sample is readily computed from moisture content and volume and is, of course, equal to the water concentration of the unknown sample.

The improved apparatus developed at the Bureau consists primarily of a "detector" (electrodes and the

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separating insulation on which the conducting film is spread, together with the necessary support), an indicating circuit involving an adjustable bridge with its power supply and amplifying device, and an indicating instrument such as a galvanometer or microammeter. Other necessary parts are a pressure-tight enclosure for the detector known as the "cell," a "saturator" for adding moisture to the reference gas, two pressure gages, a cylinder of compressed air or other gas, valves, and connecting tubing.

The detector consists of concentric, glass-insulated platinum electrodes, about 1.5 and 3 mm in diameter, mounted in a bushing that can be screwed into the cell. When the gas to be tested or the reference gas is passed into the cell, the resistance of the film deposited on the surface of the glass between the two platinum electrodes varies with the moisture in the gas, and this variation in conductance is indicated by the meter. The pressures of the two gases being compared are then adjusted until the meter readings are the same. In this procedure, the pressure gages actually serve as the measuring instruments; the meter is used only to show a null point. However, when moisture concentrations are changing rapidly, these changes are followed by means of current readings that are interpreted with the aid of a calibration curve.

The material most frequently used for the detecting film is phosphoric acid. The gas of known water content with which the unknown gas is compared is conveniently obtained by saturating air with water vapor at high pressure and expanding to any desired extent. For humidities too low to be conveniently matched in this manner, the moisture content, well below saturation, of a cylinder of compressed air is determined by comparison with air from the saturator, and the cylinder is subsequently used as a secondary standard.

It has been found practicable for an observer using this method to determine the compliance of oxygen with an exacting specification for dryness at the rate of 100 cylinders per hour. By use of secondary standards with some sacrifice of accuracy, it is possible to work with greater speed and convenience, as well as at much lower concentrations of water vapor. Changes of less than one part per million of water in Freon from a refrigeration machine have been determined in this way without difficulty at intervals of 1 minute.

A simple and convenient auxiliary apparatus has been designed at the Bureau, by means of which this method may be used to determine extremely small concentrations of water in such liquids as ether or gasoline in a few minutes. As the water concentration of a liquid of otherwise constant composition bears a definite relation at any given temperature to the humidity of air with which it is in equilibrium, the moisture concentration of a liquid may be determined quickly by measuring that of the air above it. A spring clip is applied to the detector so that a glass "test tube" with a small opening in the bottom may be quickly attached, making a snug but not airtight fit with the detector plug and covering the sensitive film. When the detector with this attachment is lowered into a bottle of the liquid to be tested, the glass tube fills with liquid from well below the surface at a rate that forces air past the detector under slight pressure. The detector is lowered until the detecting film is only a few millimeters above the liquid surface. The resistance of the detector changes rapidly at first but soon becomes practically constant when the small volume of residual air becomes saturated. As this volume is almost isolated from the surrounding atmosphere, which is itself almost in equilibrium with the liquid, there is very little disturbance by diffusion from the outside. Two or three minutes is usually sufficient to obtain a steady reading, and successive tests are reproducible.

The instrument appears to be applicable to almost any liquid; with those that produce alkaline vapors, however, an electrolyte other than phosphoric acid must be used on the detector. It is expected that this device may also prove useful in determining the moisture content of many substances—such as fats or cellulose derivatives—which are soluble in organic liquids.

The general applicability of the method to liquids suggests the possibility of determining the water in solids also. Candy can be dissolved in alcohol, butter or other grease in ether or carbon tetrachloride, and the water in the solutions quickly determined. A sample of soil, molding sand, or concrete-making material shaken with acetone may be expected to transfer

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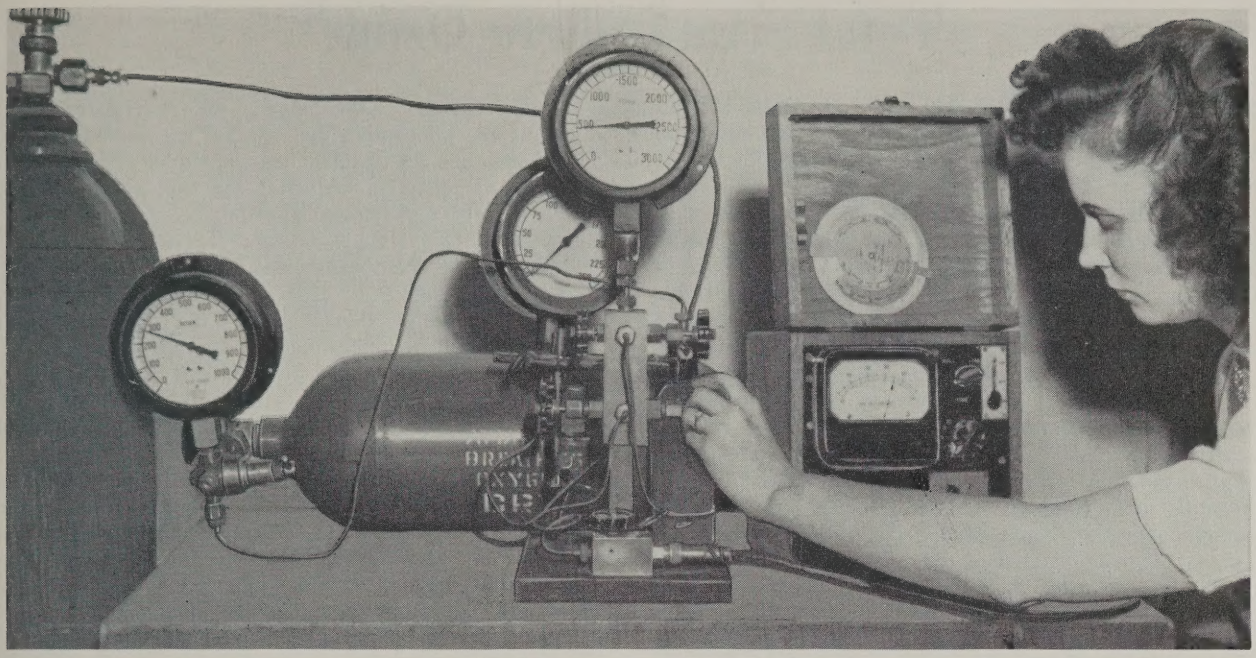


Small amounts of water vapor in gases may be determined rapidly and with great sensitivity by the change in electrical resistance of an electrolytic film as it absorbs moisture. The film is spread over the surface of a solid insulator between metallic electrodes in a pressure-tight enclosure (lower center). Changes in resistance are indicated by variations on the meter.

its surface moisture to the liquid at once. Thus it should be possible to determine quickly the surface moisture of numerous powdered or granular solids by shaking a measured sample with a suitable liquid and, without removing the solid, submerging the attachment for testing liquids in the resulting solution.

By passing dry air at a steady rate through a powdered solid and thence through the measuring cell while the resistance of the detector is recorded at short intervals, the amount of water removed from the solid may be estimated. This procedure, as contrasted with differential weighing, has the advantages of speed, sensitivity, and smallness of sample required. A similar procedure, in which saturated air is passed over a desiccant, has been found useful in determining the capacities of drying agents.

The permeability to water vapor of protective films or membranes used in packaging materials for shipment or storage is of considerable importance. The quick response of the detector to low concentrations of water in small samples adapts it to the rapid determination of permeability—not only to water, but when combined with combustion, to oxygen, hydrogen, and other substances that can be burned to produce water. The vapor barrier is clamped over an enclosed container of water at a short distance above the liquid surface. Above the barrier is an enclosed space, at the top of which is the detector. This space is connected through valves to a supply of dry air and to the outer atmosphere. Before inserting the detector, its resistance is determined in the usual way at a relative humidity of 25 percent. It is then placed in the space above the vapor barrier, and the space is swept out with a brisk stream of dried air for 1 minute. After the valves are closed, the time required for the relative humidity in the space to reach 25 percent again is an indication of the resistance of the membrane to the passage of moisture. In this way, the permeability to water vapor of a square inch of ordinary cellophane can be determined approximately in less than 1 minute after closing the valves. An advantage of this procedure is the possibility of testing very small samples of the protective barrier.

The detector has been employed, in combination with a hot platinum wire to cause combustion, for the detection of combustible gases, most of which produce water when burned. Its speed of reaction and great sensitivity suggest its use in locating leakage of fuel gas, exploring for petroleum, and detecting explosive mine gases.

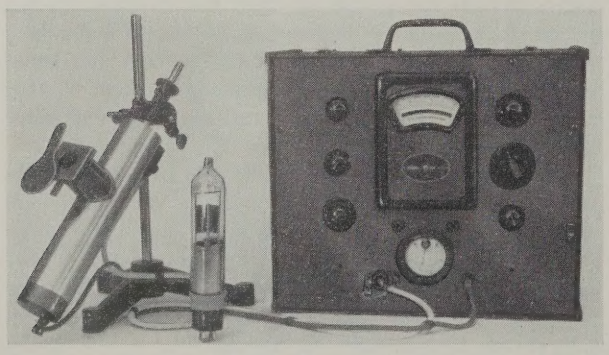
The device is not satisfactory at very high humidities and is not recommended for ordinary meteorological observations, where the instruments commonly used are less elaborate and will give as good or better results with the same attention. However, the method does have the advantages of speed of response, broad range, and ability to measure the humidity of small spaces with relatively little effect on that humidity and without the necessity of blowing air over the detector. It is also much easier to arrange for its use in places that are not readily accessible than it is with either dew-point or wet-and-dry bulb instruments.

Total Stratosphere Ozone

It is recognized that the variation in the total amount of ozone in the stratosphere has a direct correlation with latitude and season, and that different types of air masses show variations in ozone content that are associated with their origin or movement. However, it is not known at present whether any direct relationship exists between such ozone variations and current weather conditions. The development of a suitable technique for routine measurement of total ozone is of great interest in order to establish possible correlations between ozone concentrations and weather phenomena. If such correlations do exist, ozone data may become very useful in weather forecasting.

At the request of the Naval Research Laboratory, Ralph Stair of the Bureau's radiometry laboratory recently made total-ozone measurements [1] of the stratosphere over the Organ Mountains in New Mexico by means of ground-based equipment employing a photocell and selected filters. This method serves as a check upon ozone determinations by V-2 rocket flights from White Sands Proving Ground. The technique developed by the Bureau makes use of phototubes sensitive to ultraviolet radiation of wavelengths under 3,400 angstroms and filters with transmittances beginning at 2,900 to 3,100 angstroms and increasing with wavelength. As ozone is strongly absorbing within this region, the spectral energy distribution of sunlight reaching the earth's surface is greatly affected by its presence. Hence, when the transmittances of the filters are measured for sunlight (using the phototube as a detector), the observed value depends upon the solar energy distribution, and therefore is a function of the amount of ozone within the beam of sunlight under study.

The spectral energy curve of sunlight outside the earth's atmosphere may be calculated from measurements of filter transmittances of sunlight (for various altitudes of the sun) after correction has been made for Rayleigh scattering at the altitude and location of the observing station. Knowledge of the spectral response curve of the phototube, the spectral transmittances of the filters, and the spectral transmittances of selected amounts of ozone is required for this computation. When the spectral energy distribution of solar radiation outside the earth's atmosphere has been determined (within the spectral region extending from about 3,000 to 3,400 angstroms) by this method, or has been obtained from data of other observers, the total amount of ozone in the stratosphere may be derived as a function of the observed filter transmittance of a single filter. After this relationship has been established, the total amount of ozone may be determined quickly from one filter transmittance measurement.



Apparatus developed by the Bureau for determining total ozone concentrations in the stratosphere consists of (left to right) phototube mounting, titanium phototube, and ultraviolet meter. Should direct correlation be found to exist between ozone concentrations and current weather conditions, such data may become important in weather forecasting.

In the investigation at San Augustine Pass in the Organ Mountains, two phototubes and four filters were employed, providing eight independent determinations of the ozone value for the period of June 29 to July 4, 1947. The extremes of these eight determinations were about 0.19 and 0.24 cm of ozone at normal temperature and pressure (that is, if all the ozone in the stratosphere were brought to sea level and reduced to 0° C, the total thickness would be 0.19 to 0.24 cm). During this period the mean value varied from about 0.20 to 0.22 cm with changes in the type of air mass. A mean value was observed for continental tropical air, the higher value for a polar air mass, and finally the lower value for a tropical maritime air mass. The weighted mean of all determinations was 0.21 cm.

Additional measurements during the week of December 15, 1947, should give a winter value for total stratosphere ozone at the same location. These measurements will provide an independent set of ozone data for the time of the year when the sun is near its maximum declination south, while the midsummer determinations furnish data corresponding approximately to the maximum northern declination of the sun. Positive conclusions of the ozone-weather relationship can be made only after more comprehensive data have been obtained and analyzed from many different observing stations, a project that is being planned by the Weather Bureau.

Although extensive details are involved in the development of calibration curves and data for each phototube and set of filters, the Bureau's method becomes simple for routine operation at a particular observing station, after the original calibration data and curves have been prepared. Furthermore, as the auxiliary equipment consists only of a simple direct-current amplifier, the equipment for this type of work is inexpensive and easily assembled and transported to suitable observing stations. The method is therefore recommended where routine measurements of ozone concentration are to be made at widely distributed stations.

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[1] For detailed account of this work, see Measurement of ozone over the Organ Mountains, New Mexico, by Ralph Stair, J. Research NBS **40**, 9 (1948) RP1851.

Radio-Frequency Standards

A primary function of the National Bureau of Standards is to provide standards of measurement for industry and other Government agencies. In the last decade or so, the tremendous development of radio and its increasing use as a tool in other fields have emphasized the growing necessity for the development of standards and measurement methods for all electrical quantities—including frequency, power, voltage, current, attenuation, impedance, and field intensity—at all radio frequencies from 10 kilocycles up to 100,000 megacycles or more. National standards need to be derived from and agree precisely with the fundamental units of measurement, and it is essential to science and industry that agreement be secured on these standards throughout the world. In the continuous task of setting up and maintaining such standards, the National Bureau of Standards has taken the lead, both in developing new and improved standards and in increasing the accuracy of those already available.

The work of the Bureau in radio measurements and standards is basic not only in the older frequency ranges but also in opening up and fully exploiting the vast new microwave spectrum now available. Measurement methods, equipment, and standards for calibrating such equipment are necessary working tools for the design, development, and production engineering of practical apparatus, as well as for pure and applied research. In fact, the production of tubes, transmitters, receivers, and other radio-system components would not be possible without adequate measurement techniques.

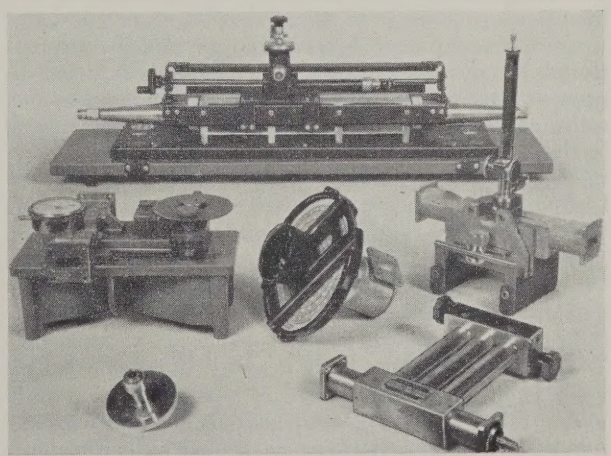
Radio standards and measurement are thus of fundamental importance in the design and development of improved equipment for global aviation and many vital military instruments. Good standards of frequency are likewise essential to the effective allocation of frequency bands and in meeting the strict frequency tolerances required for broadcasting and international communication. In the field of atomic energy and nuclear physics, many of the new techniques for producing high-energy particle beams, including the waveguide accelerator, the synchrotron, the resonator accelerator, and the cyclotron, depend upon radio methods, especially microwave methods, in which highly accurate standards are necessary. Radio standards are also of great value in the development and proper use of equipment for various industrial and medical applications of radio and electronics, such as dielectric heating for case-hardening metals, tire curing, plastic molding, food processing, textile fabrication, and radiotherapy.

The Bureau's program on radio-frequency standards includes: (1) The development of primary electrical standards and the theory and methods of measurement required to utilize these standards, (2) the establishment of a service for calibrating unknown secondary standards against the Bureau's primary standards, and (3) the design and improvement of various measuring instruments. In carrying out this program, each electrical quantity at radio frequencies is accurately determined by reference to basic physical units, primary standards are carefully designed and built to have extreme stability under all operating conditions, and techniques are developed to give a high degree of measurement accuracy and reproducibility. Good agreement is also required between related standards based on different principles.

Frequency Standards

The national standard of frequency, of which the Bureau is the custodian, is fundamental to much of the work in radio, electronics, acoustics, and other fields where measurements and operations require accurate frequencies. Any desired frequency, including those throughout the microwave region, may be precisely measured by reference to the standards broadcast by the Bureau's station WWV, with the aid of one or more auxiliary oscillators, harmonic generators, and radio receivers. The accuracy of each of the transmitted radio and audio frequencies is better than two parts in 100 million.

The basic frequency standard is the average rotational frequency of the earth (0.0000116057615 cycle per second). This is obviously too low for radio and electronic work; nevertheless precise average agreement with it is maintained. Eight quartz-crystal oscillators with series-resonance frequencies of 100 kilocycles are continuously operated and continuously compared with their weighted mean value and with corrected U. S. Naval Observatory time. Standard frequencies of 10 kilocycles, 1 kilocycle, 100 cycles,



Measuring instruments and secondary standards in the microwave-frequency range include coaxial slotted line (A); waveguide, metallized-glass attenuator (B); cavity frequency meter (C); waveguide slotted line (D); coaxial, thermistor load impedance (E); and three-stub, coaxial impedance transformer (F).

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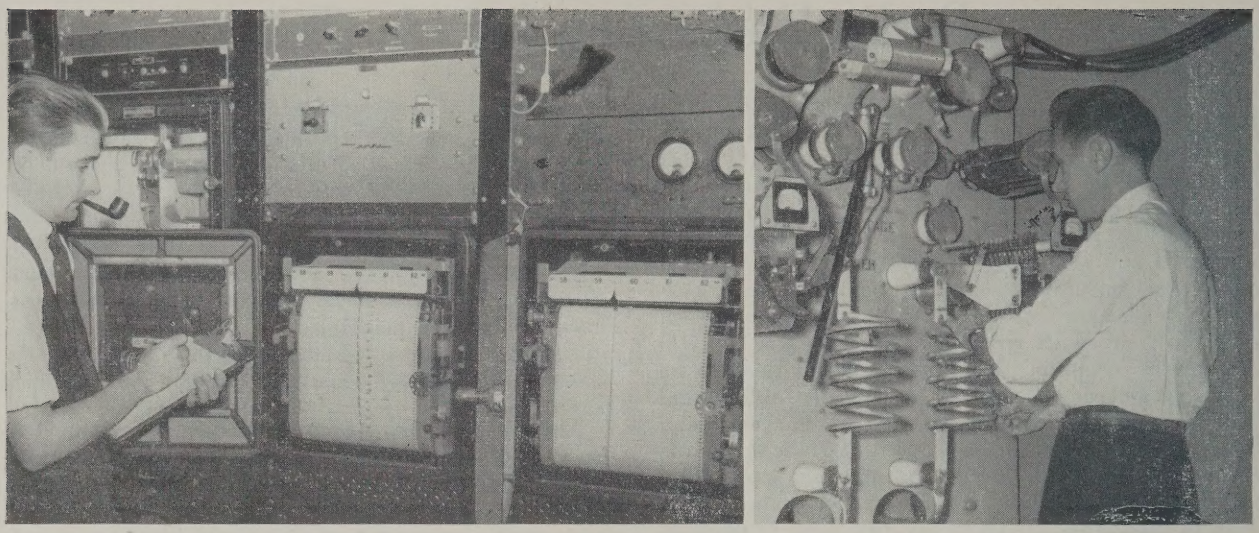


Small differences between the primary frequency standards are recorded automatically (left). Changes of 1 part in 10 billion can be indicated. Any desired frequency may be precisely measured by reference to the standards broadcast by the Bureau's radio station WWV (right). The accuracy of each of the transmitted radio and audio frequencies is better than 2 parts in 100 million.

60 cycles, 10 cycles, and 1 cycle are given by frequency dividers or counters, and frequencies at closely spaced intervals up to 30,000 megacycles and higher are obtained by multipliers. The standard 60-cycle frequency supplies power to a synchronous motor which, through gear trains, drives contacts that make possible the broadcasting of highly accurate time signals throughout the world—the only continuous service of this kind provided by any country. To insure the maintenance of constant frequency, the crystal-units are sealed in well insulated boxes and kept in a vault approximately 25 feet below the surface of the earth, under conditions of constant temperature and humidity. The best oscillators are constant to one part in a billion and drift less than one part in a hundred million per month.

Constant-frequency generators now under construction at the Bureau will conveniently supply 0.1 watt or greater at any frequency, constant to one part in ten million, with practically no harmonic distortion. Such generators are needed for rapidly measuring unknown frequencies. They will also be used to measure high-Q components, such as piezoelectric crystal units, which are in turn used in precision frequency standards.

Power, Current, and Voltage Standards

In general, laboratory measurements of power below 1 watt are classed as "low power," those above this value as "high power." Low rf powers, starting with a few microwatts, are accurately compared with dc or audio frequency powers by means of bolometers, thermistors (small glass-like semiconductors having a large change in resistance with temperature), or small-diameter platinum wires suitably mounted and connected in precision dc bridges. Under careful temperature control, agreement of the order of 1 percent is obtained between these methods at frequencies up to 100 megacycles, and in several narrow bands in the microwave region. Work is now under way to establish power standards in the band from 300 to 3,000 megacycles and in the 9,000-megacycle range.

High power, ranging up to kilowatts for continuous waves and up to megawatts for pulses, is measured by conversion to heat, e. g., in a water load. The quantity of heat is then determined by calorimetric methods using basic standards of heat. Such methods are also being used to check the microwave standards designed for high-power measurements.

The NBS high-frequency current standards for small currents (up to 0.5 ampere) are at present based on thermal ammeters, thermistors, and current-measuring lamps. These methods are accurate to ± 3 percent at frequencies up to 100 megacycles. Work is in progress on what is essentially a current transformer to extend the range to about 100 amperes. This method employs a uniform section of transmission line and an accurately calibrated attenuator coupled to the line at a maximum current point. Unfortunately, rf ammeters and voltmeters become more difficult to design and less accurate as frequency is increased. Thus, for accurate results at frequencies above about 30 megacycles, current standards are generally obtained from measurements of power and impedance unless the ammeters can be calibrated in place at a given frequency.

The accuracy, frequency, and range of voltmeters and standard voltage generators have been greatly extended at the Bureau. As with power measurements, laboratory standards and measurement techniques are determined by the voltage magnitude. Below a few volts, standards have been established with precision barretters, thermistors, or bolometers, and attenuators of known ratio. These instruments give agreement to ± 5 percent or better for voltages as low as 1 microvolt

at frequencies up to 100 megacycles. Higher voltages are measured to ±1 percent by means of capacitive dividers and cathode-ray oscilloscopes. Special oscilloscopes, which are being built for accurate measurement of voltage and pulse amplitudes, will also provide additional checks on the low-frequency standards.

Impedance Standards

The impedance of many radio components, such as resistors, coils, and transmission lines, can be accurately calculated if dimensions, materials, and surrounding conditions are known. However, this fundamental property of circuits is usually measured in terms of standards or with standardized instruments. Rf bridges are employed up to about 30 megacycles, and can be extended to perhaps 100 megacycles by use of special techniques and reduced range. They are accurate and convenient and have a wide range.

Instruments for higher frequencies using so-called lumped-constant resonant circuits, known as Q meters, have a useful impedance range. They are employed for frequencies up to 200 megacycles, but because of numerous sources of error require standardization before use in precision work.

Distributed-constant circuits, consisting of short resonant sections of line, resonant cavities, "magic tees," uniform slotted lines, and waveguide Wheatstone bridges, constitute the VHF and microwave impedance measuring instruments and standards. With an 8-foot solid-dielectric precision line, accuracies of ±5 percent are obtained between 50 and 300 megacycles in the range from 5 to 500 ohms. A specially constructed thermistor bead mount, connected to a self-balancing bridge oscillator circuit, is used as a standard to check these results. Improved accuracy is expected from a resonant line method being developed.

Field-Intensity and Antenna Standards

In practice, the accuracy of field-intensity measurements is limited by unknown ground conditions, proximity of instruments to receiving antenna, and random variations in received fields due to changes in the transmitting medium. However, high accuracies have not thus far been required by the radio industry.

The intensities of standard fields are calculated from accurate knowledge of radiating systems, including the current or power input. Equipment for generating standard rf fields is also in regular use at frequencies up to about 30 megacycles, providing accuracies of ±1 percent. At higher frequencies, improved techniques for measuring antenna currents are being tested, and the necessary standard antennas, of known radiation pattern and power gain, are being developed in preparation for instrument calibration.

Attenuation Standards

Attenuators are needed in nearly all rf measurement work. On special instruments such as field-intensity meters or signal generators, the attenuator serves as the standard of voltage or power ratios. Good attenuators must have wide frequency band, constant impedance, small-step or continuous adjustments, and accurate indication. Other useful characteristics are low insertion loss and a power dissipation of several watts.

Dielectric properties of materials at very high radio frequencies may be measured with fixed-length reentrant resonant cavities. The small cavity (right) is used in the 400 to 600 megacycle frequency range, the large cavity in the 150 to 300 megacycle range. Circular disks (foreground) function as capacitor dielectrics in the reentrant gap of the cavity.

The NBS attenuation standards are of several types. The first consists of a group of four-decade wire-wound attenuators having 0.01-decibel intervals up to 111 decibels. After standardization at direct current by the Bureau's electrical instruments laboratory, the frequency error of this group at radio frequency was found negligible up to 7 megacycles. A second type is a mutual-inductance (piston) attenuator having a continuously adjustable range of 120 decibels, a sensitivity of better than 0.01 percent, and no frequency error up to about 1,000 megacycles. Piston attenuators are absolute standards whose indications can be accurately calculated from materials and dimensions. A third type, designed for fairly wide regions of the microwave spectrum, employs a conducting film on glass, which is inserted or removed in the electric field of a wave guide.

Attenuation standards have been developed for frequencies including those in the microwave region by the heterodyne method, in which an unknown attenuation at radio frequency is compared with a standard attenuation produced by a waveguide-below-cutoff unit at an intermediate frequency. The theoretical attenuation constant has been verified to one-hundredth of a decibel, the highest accuracy attainable at present. The heterodyne method used in conjunction with such a standard is capable of giving precision results over an attenuation range of 40 to 50 decibels, and by use

of a calibrated attenuator in the rf channel, this range can be greatly extended. It is expected that the Bureau will offer calibration services for attenuators during the coming year.

Dielectric and Magnetic Measurements

Both resonant-cavity and impedance methods are to be used in the program developed at the Bureau for dielectric and magnetic measurements. Work on solid, liquid, and gaseous materials has begun, and already new precision measurements in the 9,000-megacycle range have been made of the dielectric constant or index of refraction of many gases, including dry air, water vapor, oxygen, nitrogen, carbon dioxide, helium, and ammonia. An instrument has been developed for recording continuously both the loss angle (or power factor) and the dielectric constant of a material. This method, together with another procedure utilizing two cavity-stabilized oscillators beat together, is being used to make a microwave refractometer, a device for measuring continuously the index of refraction of a gas (in particular, atmospheric air). Such measurements are important in propagation studies. It is expected that equipment of the impedance type will soon be available for measuring liquid and solid dielectrics in the microwave region.

Radio Noise Standards

Known standards and accurate measurement methods for electrical noise are of basic importance in radar, in telemetering, and in radio control, research, and basic communication, as limitations on reliability, sensitivity, and distance range are set by the type and magnitude of noise in the equipment as well as in the transmitting medium. In general, such interference is of five types: (1) Continuous sine wave (used mainly in radio broadcasting); (2) periodic pulses like those from radio navigation devices or spark ignition systems; (3) random pulses or noise from thunderstorms, electrical machinery, and similar causes; (4) "fluctuation noise", which is spontaneously generated in all electrical circuits, and "shot noise" associated with electronic tubes; and (5) solar and cosmic noise from the sun and interstellar space.

Accurate methods of generating and measuring such disturbances, either separately or combined, are being investigated at the National Bureau of Standards. These methods involve the use of frequency, power, field-intensity, attenuation, and impedance standards. Techniques have been developed for measuring the noise figures of radio receivers and other networks by means of special standard noise tubes (temperature-limited diodes). Accuracies of about ±20 percent at frequencies up to 150 megacycles are now being obtained in this work. At microwave frequencies the problem of generating, terminating, and using a known source of a given kind of noise is much more difficult. Special waveguide noise-generating tubes are now being developed for the microwave bands.

Development of Improved Standards

Standards and measurement techniques of reasonably high accuracy are now available up to a few tens of megacycles and in specific bands at microwave frequencies. In the future, increased accuracy, frequency, and magnitude will be sought, and precise instruments of all types will be accepted for standardization at a nominal fee. Efforts will also be made to develop highly accurate portable instruments that will quickly and conveniently determine the electrical characteristics of materials and of precision instruments under known conditions.

The Bureau plans to cover the complete radio spectrum in a systematic manner without gaps in frequency or range of quantity measured. However, improvement of accuracy is a never-ending task. The present frequency standards, for example, are excellent, but their high accuracy has been found insufficient for certain special applications where constancy of one part in ten billion or better is needed. Indications are that another order of accuracy may be obtained with quartz crystal-controlled oscillators by development of more constant and higher-Q crystal units operating at extremely low amplitudes. For some frequency standards work, the resonances associated with atoms may be found more convenient, especially for microwave frequencies. Atomic resonance techniques already developed give accuracies approaching one part in a million, and results are free from changes in temperature, pressure, or purity of materials.

In maintaining primary frequency standards, long-interval agreement with motions of heavenly bodies is necessary. Fortunately the services of the nearby U. S. Naval Observatory are promptly available to the Bureau for this purpose. For all other standards, such as power and voltage, independent methods of checking are to be developed.

The Bureau encourages international comparisons of all rf measurement standards. This may be done for frequency standards through radio station WWV, but international comparisons of other quantities at radio frequencies, which are much more difficult to measure and subject to greater error, are lacking. The necessity of thus checking attenuators, field-intensity meters, voltmeters, ammeters, power meters, standard-voltage generators, and impedance-measuring apparatus is obvious for any comprehensive long-range standards program.

Information and Coordinating Services

In carrying out its radio frequency standardization program, the National Bureau of Standards maintains close liaison with the Army, Navy, Air Force, industry, and educational institutions. This is accomplished through publication of reports, through testing and advisory services, through comittee representation on the Research and Development Board, the Aeronautical Board, and the Joint Communications Board of the Department of National Defense, and through committees of technical groups such as the American Institute of

Electrical Engineers and the Institute of Radio Engineers.

An extensive library of reports on microwave measurement work in all parts of the world is being constantly augmented. This library is a valuable aid to the Bureau in its function as an information and coordinating center in the microwave field, where enormous military, industrial, and scientific potential exists.

Current Efficiency in Electrochemical Processes

A new method for measurement of the current efficiency of an electrochemical process [2] has been developed by W. J. Hamer of the Bureau's electrochemistry laboratory in connection with studies of isotopes. The method is based on principles previously utilized at the Bureau in the separation of natural isotopes by a technique known as countercurrent electromigration [3] in which an imposed flow of electrolyte through a packing in a direction opposite to ionic migration carries back the slower moving ions of the heavier isotopes.

Electrochemical processes are being used more and more in industry for the preparation of a variety of materials. Chlorine and other gases, including a number of paraffin hydrocarbons, are obtained in this way. Electrochemical processes are also employed in the electrorefining of metals and in electrolytic oxidations or reductions.

In many of these processes simultaneous reactions take place at an electrode. Where this occurs, the ratio of the number of equivalents of a single electrode product to the total possible number is called the current efficiency of the electrochemical process under investigation. Variations usually occur in ionic composition or concentration in the vicinity of the electrodes, due to electrolysis and ion transport. Because of such variations, precise values of the current efficiency cannot be obtained, and the process cannot be carried on continuously with either constant current efficiency or constant yield.

For example, when a concentrated solution of brine is electrolyzed between graphite electrodes, a gaseous mixture of chlorine and oxygen is generated at the anode. At first, this mixture may contain, say, 98 percent of chlorine and 2 percent of oxygen; the current efficiency for the production of chlorine would then be 98 percent. However, as electrolysis proceeds, the concentration of chloride ion in the brine becomes less from loss of chlorine gas, and the current efficiency for the production of chlorine decreases correspondingly, eventually becoming almost zero. Mixing of the products at the electrodes also lowers the efficiency of the process. As a result, the over-all efficiency may be only 50 percent, with an attendant increased cost of production.

Many types of electrolytic cells have been used commercially to increase current efficiency in the production of chlorine gas—a result that may also be achieved with the apparatus developed at the Bureau. This apparatus consists essentially of a cell with flowing electrolyte, in which there is no net transfer of ions and in which the concentration of the electrolyte is kept constant during the electrolysis. Current efficiency is thus maintained at the initial level.

This apparatus has been used to determine current efficiency, for various concentrations of electrolyte, in the electrolysis of uranyl chloride. The process takes place within a U-shaped electrolytic cell consisting of vertical anode and cathode compartments separated by a horizontal tube containing a porous glass-wool packing or diaphragm. The purpose of the packing is to separate the anodic and cathodic compartments and thus prevent the formation of chlorites, chlorates, etc., or a reversal of the electrolytic processes because of mixing. To avoid contamination of the cell electrolyte with reduced products of uranyl chloride, the cathode is isolated from the uranyl chloride by immersion in a layer of hydrochloric acid, which forms a sharp boundary with the uranyl chloride solution. During electrolysis, known concentrations of hydrochloric acid and uranyl chloride are added at the cathode and anode, respectively, at such rates that losses of electrolyte at the electrodes due to electrolysis and ion transport are prevented. An overflow is provided at the anode to carry off the added solutions at a rate equal to the sum of the rates of addition of hydrochloric acid and uranyl chloride, thereby inducing an electrolytic stream flow in the cathode-to-anode direction. After equilibrium is established, the gas generated may be collected in a gas pipette or other suitable container and analyzed chemically to determine the current efficiency.

When platinum and other metals of the platinum group were used as anodes, analysis of the evolved gas showed about 97, 88, and 45 percent of chlorine, respectively, for 0.9-, 0.5-, and 0.1-normal solutions of uranyl chloride. The yield of chlorine was somewhat less with anodes of baser materials such as magnetite, metallic carbides, and graphite. The percentage of chlorine in the evolved gas is independent of current density except for the most dilute solution, where a decrease in current density increases the percentage of chlorine.

As production of chlorine by electrolysis of uranyl chloride may thus be continued indefinitely under controlled conditions, the method might well be adapted to the production of gases, such as chlorine, hydrogen, deuterium, and oxygen, in lots of known purity. It is also expected that, with some mechanical changes, these principles may be applied in the continuous refinement of metals and in electrolytic oxidation or reduction processes.

[2] For further technical details, see Anodic current efficiency in the counterflow electrolysis of uranyl chloride solutions, W. J. Hamer, J. Research NBS **39**, 141 (1947) RP1817.

[3] Isotope separation by countercurrent electromigration, NBS Technical News Bulletin **31**, 49 (1947).

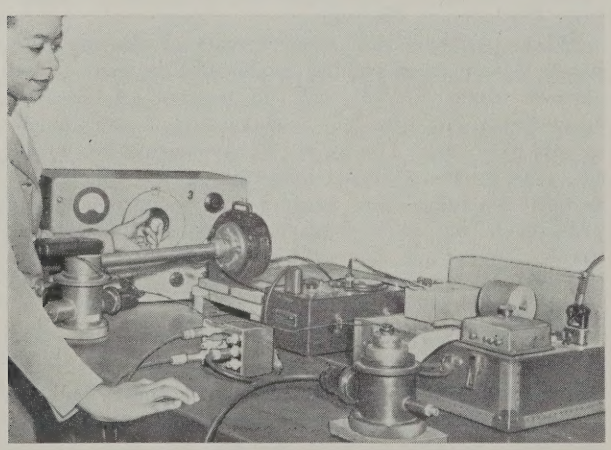
Cavity Pressure Determination of Hearing Aid Gain

A procedure for measuring the gain of hearing aids, recently developed by the Bureau's sound laboratory, offers to manufacturers and commercial laboratories a useful and economical method for maintaining adequate quality control of hearing aids. The apparatus, utilizing a cavity pressure method,[4] permits a compact test setup and therefore is much simpler than that required by the free-field procedure now in general use. Because the equipment may be constructed at extremely low cost as compared to an expensive sound-insulated, echoless room, closer control of the gain performance of hearing aids should now be readily available even to the smaller manufacturers.

The gain of a hearing aid, probably the most important single factor in its performance, may be defined as the ratio between the sound level transmitted to the ear of the user by the receiver and the level of the sound impinging on the microphone of the hearing aid. The ear of a hard-of-hearing person is less responsive to sound stimuli than a normal ear, and the gain is a measure of the magnification of sound stimuli available to the user of a hearing aid. Hence the magnitude of the gain is directly related to the maximum severity of hearing loss that a hard-of-hearing person may suffer and still derive benefit from the use of the instrument.

Though the definition of gain is forthright, its measurement is complex and indirect. It involves measuring the sound pressure actually impinging on the microphone of the hearing aid and the sound pressure produced in the ear of the user by the hearing-aid receiver.

A major difficulty in testing a hearing aid and the chief expense for testing equipment are encountered in the quantitative determination of the sound level applied to the microphone of the hearing aid. In the free-field procedure in common use, a pure-tone signal from an electronic oscillator drives a loudspeaker. The hearing aid is suspended facing the speaker so that it receives sound radiated from the speaker.



The cavity pressure method for measuring the gain of hearing aids is considerably simpler and less expensive than the free-field (echoless room) method now commonly used to determine this important performance factor.

Because the distribution of sound radiation from a speaker is nonuniform, that is, it possesses a directional pattern that varies strongly with frequency, it is not feasible to compute the sound pressure incident on the hearing-aid microphone. It is therefore necessary to measure the sound radiated by the speaker at the point in space occupied by the hearing-aid microphone. For this purpose, a calibrated microphone is substituted at the position to be occupied by the hearing aid. The sound pressure indicated at each frequency by the measuring microphone is taken to be the sound pressure incident at the face of the hearing-aid microphone.

For these measurements to be valid, sound must come only from the speaker with no spurious effects introduced by reflection of sound from the walls, floor, or ceiling of the test room. The interior surfaces of the test chamber must therefore be built of material having a very low reflection coefficient for sound waves. Moreover, the volume of the room must be large to minimize reflection, and sounds originating outside the test chamber must be excluded. The construction of an "anechoic" chamber with highly absorbent walls and a sound-isolating structure is expensive. Acoustic materials exhibiting low reflection and high sound absorption are fragile and delicate and must be carefully protected. A good chamber can be constructed at an expenditure of the order of a hundred thousand dollars, though measurements can be made over a limited frequency range with a less effective anechoic chamber built at a cost of perhaps twenty thousand dollars.

Although the Bureau has an anechoic chamber of adequate quality, it was necessary to devise some means for testing hearing aids that would release the test room for other work. The new procedure utilizes a system analogous to a piston and cylinder for applying the incident sound pressures to the hearing-aid microphone. The face of the hearing aid and a calibrated measuring microphone are made, in effect, part of the cylinder wall. They are mounted as flush closures on opposite sides of a small cavity cut into a heavy brass block. The driver unit of a loudspeaker serves as the piston generating the pressure alternations of a sound signal in the air volume enclosed by the source cavity. It is coupled to the source cavity via a brass tube. For sound frequencies low enough for the pressure alternations in the cavity to be instantaneously uniform throughout the cavity volume, the indications of the measuring microphone are a direct measure of the sound levels applied to the hearing-aid microphone. The frequency range is extended to higher frequencies, at which the sound pressure in the cavity is not altogether uniform, by mounting the measuring micro-

[4] For further technical details, see A cavity pressure method for determining gain of hearing aids, E. L. R. Corliss and G. S. Cook, J. Research NBS **40**, 85 (1948) RP1857.

phone and the hearing-aid microphone symmetrically with respect to the speaker tube.

The output sound level produced in the ear of the user by the receiver of the hearing aid is measured by the same technique in both the old and the new procedures. Ears differ in size and shape, and so the load that they present to the receiver differs from one individual to the next. However, an "artificial ear" has been devised [5] which contains a measuring microphone in a position corresponding to the tympanum of the human ear, and which presents to the receiver of the hearing aid a load representative of a human ear fitted with an ear mold. Comparison with measurements on human subjects has shown that this "artificial ear" provides a valid though rather inexact means for measuring the output of the hearing aid receiver. The differences between the results obtained by using the artificial ear and those obtained with human subjects are sufficiently small that they do not mar the significance of the data obtained using the objective method.

[5] Frank F. Romanow, Method for measuring the performance of hearing aids, J. Acoustical Soc. Am. **13**, 294 (1942).

The equipment required in the cavity pressure method for applying known sound levels to the microphone of a hearing aid may be simply constructed in a machine shop. The entire source cavity unit, including the calibrated standard microphone, its associated amplifier and output meter, the speaker unit, and signal oscillator can probably be assembled at an expenditure of a few hundred dollars. The cost of a complete "artificial ear" including the measuring microphone and its associated amplifier and output meter, and a small brass block of which the "ear canal" is constructed, is of the order of several hundred dollars.

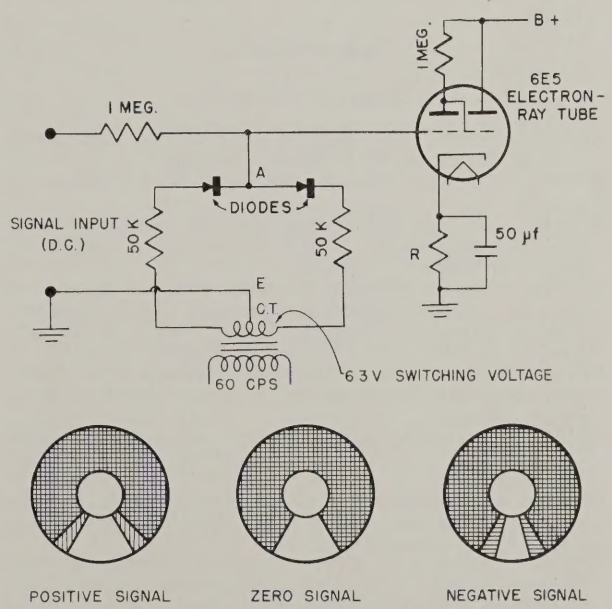
The construction and maintenance of a specially treated echoless room is expensive, prohibitively so for many manufacturers. Both manufacturer and purchaser suffer if a defective instrument reaches the market. The simpler test procedure developed at the Bureau provides a more economical means of testing hearing aids, and one that can easily be adopted by any manufacturer. Societies for the hard-of-hearing should also find it possible to use such a technique for checking the instruments owned by their members.

Polarity Response From Radio Tuning Eye Tubes

The use of electron-tube tuning indicators for balance or null detectors is well known. The necessity for polarity-sensitive tuning indication in frequency modulation reception has given impetus to the development of the new 6AL7–GT indicator tube, featuring a dual column type of presentation. For instrument work, however, a balance indicator capable of greater precision is frequently desired. By means of a special circuit M. L. Greenough of the Bureau's electronic instrumentation laboratory has adapted a conventional "magic eye" tube of the variable shadow angle type, such as the 6E5, 6U5, and 6N5, to furnish a polarity-sensitive indication. Although this circuit was developed for instrument application, it may be of value for adapting a conventional tuning eye to balance indication in FM discriminators.

The obvious method of making the "magic eye" tube polarity-responsive is to bias the deflection grid to produce some arbitrarily chosen reference angle, which is marked on the scale over the tube. Positive or negative signals then cause an increase or a decrease of this shadow angle. The disadvantages of such a system are the instability of the reference angle, which is greatly dependent upon the supply voltages, and parallax of observation. These disadvantages may be avoided by repeatedly switching the signal on and off at a rate fast enough to prevent visible flicker, for example, at power line frequency. By this means two shadow angles are maintained on the tube screen itself. One shadow angle, corresponding to zero input, appears half the time, and during the remaining time the angle is that due to the amplitude of the applied signal. Zero signal input is indicated when the edges of these angles coincide.

Typical patterns are obtained for positive, zero, and negative signals. There appears to be a half-illuminated angular sector whose width is proportional to the deflection signal, and which lies on one or the other side of a reference line as determined by signal polarity.



A conventional "magic-eye" tube, when used with the special electronic circuit above, furnishes a polarity-sensitive indication (typical patterns, below) useful for precision instrument work and of possible application in FM receivers.

Alternatively, the pattern may be considered as two superimposed areas of half-illumination, one fixed and one variable. The edges of these areas are similar and sharp in the 6E5. Their superposition at balance can be precisely observed. Accurate null indication is maintained in spite of supply voltage variations, because such changes merely affect both illuminated areas identically. Using reasonable care it has been found possible to repeat observations of balance to less than 0.05 volt with the unaided eye. A simple lens permits resolution approaching an electrically imposed limit, which in this case was measured to be approximately 7 millivolts. Although no extended study of ultimate balance limitations has been made, higher magnification and improved switching circuits could undoubtedly provide higher resolution.

In the circuit the diode network acts effectively as a switch that is opened and closed during alternate half cycles of the 60-cycles per second "switching voltage." The direct-current input signal is applied across the 1-megohm resistor in series with the resistance of the diode switching circuit between point A and ground. The voltage across the diode switching circuit is applied to the grid of the tuning eye. During the half cycle of switching voltage, which renders the diodes conducting, the resistance between point A and ground is low relative to 1 megohm. This permits a negligible fraction of the input voltage to appear between point A and ground. During the half cycle of diode nonconduction, the resistance of each diode is increased to its reverse voltage value, and nearly the entire input voltage appears between point A and ground. Due to the symmetry of the diode network, none of the switching voltage appears between point A and ground.

In this circuit diodes of high quality, particularly with regard to back resistance, provide maximum sensitivity of indication. Miniature dry disk rectifiers, for example, 7-mm selenium or copper oxide units having more than 10 megohms back resistance, have proved satisfactory.

NBS Publications

Periodicals [6]

Journal of Research of the National Bureau of Standards, volume **40**, number 1, January 1948. (RP1850 to RP1857, inclusive).

Title page, corrections and contents for volume **38**, Journal of Research, January to June 1947 (RP1758 to RP1806, inclusive). 5 cents.

Technical News Bulletin, volume **32**, number 1, January 1948. 10 cents.

CRPL-D41. Basic Radio Propagation Predictions for April 1948. Three months in advance. Issued January 1948. 10 cents.

Nonperiodical

Research Papers [6, 7]

RP1842. Sorption of nitrogen and water vapor on textile fibers. John W. Rowen and R. L. Blaine. 10 cents.

RP1843. Sieve tests of metal powders. Rolla E. Pollard. 15 cents.

RP1844. Table and Mollier chart of the thermodynamic properties of 1, 3-butadiene. Cyril H. Meyers, Carl S. Cragoe, and Eugene F. Mueller. 20 cents.

RP1845. Heats, equilibrium constants, and free energies of formation of the alkylcyclopentanes and alkylcyclohexanes. John E. Kilpatrick, Helene G. Werner, Charles W. Beckett, Kenneth S. Pitzer, and Frederick D. Rossini. 15 cents.

RP1846. Factors affecting operation of apparatus for counting alpha particles in an ion counting chamber. F. J. Davis. 10 cents.

RP1847. A statistical analysis of some mechanical properties of manila rope. Sanford B. Newman and John H. Curtiss. 10 cents.

RP1848. Voltage anomalies of the glass electrode and the chemical durability of the glass. Donald Hubbard and Gerald F. Rynders. 10 cents.

RP1849. Instability of simply supported square plate with reinforced circular hole in edge compression. Samuel Levy, Ruth M. Woolley, and Wilhelmina D. Kroll. 10 cents.

Circulars [6]

C466. American Standard specification for dry cells and batteries (Leclanche type). (ASA C18–1947). 10 cents.

Commercial Standards [6]

CS45–47. Douglas fir plywood. (Supersedes CS45–45). 10 cents.

CS140–47. Testing and rating convectors. 10 cents.

CS142–47. Automotive lifts. 10 cents.

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A variable-span flexure test jig for plastic specimens. B. M. Axilrod, R. W. Thiebeau, and G. E. Brenner. ASTM Bulletin (American Society for Testing Materials, 1916 Race Street, Philadelphia 2, Pa.) No. 148, 96 (October 1947).

Damping characteristics of dashpots. John B. Peterson. Product Engineering (330 West Forty-second Street, New York 18, N. Y.) **18**, No. 11, 138 (November 1947).

Infrared spectrometry from 15 to 25μ. Earle K. Plyler. J. Optical Soc. Am. (57 East Fifty-fifth Street, New York 22, N. Y.) **37**, 746 (1947).

On the intensity of the light reflected from or transmitted through a pile of plates. L. B. Tuckerman. J. Optical Soc. Am. **37**, 818 (1947).

Condensation in buildings. Richard S. Dill. Heating and Ventilating (148 Lafayette Street, New York 13, N. Y.) **44**, No. 12, 70 (December 1947).

Electronic preserves. P. J. Franklin and M. Weinberg. Scientific American (24 West Fortieth Street, New York 18, N. Y.) **177**, 258 (December 1947).

The gravimetric (weighed-cell) method for determining water-vapor permeability. F. T. Carson. Paper Trade Journal (122 East Fortieth Street, New York 16, N. Y.) **125**, No. 19, 118 (November 6, 1947).

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[6] Send orders for publications under this heading only to the Superintendent of Documents, Government Printing Office, Washington 25, D. C. Annual subscription rates: Journal of Research, $4.50 (foreign $5.50); Technical News Bulletin, $1.00 (foreign $1.35); Basic Radio Propagation Predictions, $1.00 (foreign $1.25). Single copy prices of publications are indicated in the lists.

[7] Reprints from December Journal of Research.

[8] These publications are not available from the Government. Requests should be sent direct to the publishers.

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